CABLE CARRIER SYSTEMS AND CARRIER FREQUENCY TRANSMISSION THROUGH CABLES

CONTENTS

1. GENERAL

1.1 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers' telephone systems. It discusses in particular considerations in the application of cable carrier systems.

1.2 Since about 1958, low cost cable carrier equipment has been finding use in rural telephone plant and the purpose of this section is to explain its use and application on rural telephone systems. Low cost cable carrier equipment means that it competes favorably with physical circuits for distances as low as ten miles under certain conditions. The development of low cost cable carrier systems is due to a number of factors, the most significant being the use of transistors in carrier repeaters which eliminates the need for 117 volts a.c. power at each repeater point or at frequent intervals in a repeater string. Aside from this, the types of modulation, methods of signaling, etc., are similar to those found on open wire line carrier which have been used extensively in rural plant.

1.3 A relatively new concept, adopted by a number of manufacturers, makes little distinction between carrier for trunk use and subscriber use. The obvious difference being in the signaling functions of the two types of carrier. Otherwise the circuitry for modulation of voice and signaling frequencies to carrier derived frequencies, channel frequency responses, the repeatering of carrier frequencies, etc., is identical. Some manufacturers have narrowed the signaling difference between trunk and subscriber carrier by introducing loop dial signaling for trunk carrier which functionally is the same as subscriber signaling. Signaling options available are covered in this section.

1.4 The types of cable carrier equipment under consideration in this section primarily includes the types which have an operating range of up to about 25 miles between carrier terminals and cost between $1000 to $1300 per channel in fully equipped systems. In this section they will be referred to as low cost cable carrier systems. This section also briefly discusses those types of carrier systems which can span distances up to 200 miles and which, of course, are somewhat more expensive on a per channel basis. The section does not discuss Time Division Equipment (such as pulse code modulation) which to date has had little application by the independent telephone industry.

1.5 Low cost cable carrier systems were introduced as early as 1958. REA borrowers began purchasing these systems in 1960. At present, numerous systems have been in operation for more than two years and although this is a relatively short period of time for full evaluation, thus far most of this equipment has provided satisfactory service. In the fall of 1962 REA added carrier equipment to its List of Acceptable Materials and various types of low cost cable carrier equipment were included.

1.6 Much of the low cost carrier equipment discussed in this section has found application as multiplex equipment on radio channels. The send and receive levels of these carrier systems are compatible with radio requirements. For radio system requirements under 100 channels, the use of low cost carrier equipment results in substantial savings in multiplex equipment. Although the primary use of radio is for deriving trunks, subscriber cable carrier equipment can be used just as well on radio for subscriber use. Refer to TE & CM-930, "Use of Point-to-Point Radio in Telephony," Addendum No. 1, for additional information.

1.7 A large portion of this section is devoted to far-end crosstalk loss through cables which meet REA specifications where it is necessary to consider multisystem carrier applications.

2. DESCRIPTION OF CABLE CARRIER SYSTEMS

2.1 Low cost cable carrier systems are possible due to the relatively low cost of repeaters required along the cable to overcome the high attenuation at carrier frequencies. This includes the ability to power repeaters from end terminals. This is usually accomplished by feeding power to repeaters by simplexing one of the pairs to feed repeater current to one half the repeaters and then return the circuit over a simplex circuit using the other cable pair of the system for powering repeaters in the opposite direction of transmission. Figure No. 1 shows two methods used in powering repeaters. Thus, no more than two or three cable pairs are required for cable carrier systems for transmission of carrier frequencies from one terminal to another plus being able to power the required number of repeaters from each terminal.

2.2 By grouping the frequencies for each channel adjacent to each other in the spectrum for each direction of transmission, broadband amplifiers can be used as repeaters. Two amplifiers working in opposite directions constitute a repeater. By making the carrier system physical 4-wire operation (2 pairs required per system) and not utilizing the physical circuits for voice frequency transmission no directional filters are required at terminals or repeaters and the cost per repeater is thus very low.

2.3 There are also carrier systems designed primarily for open wire application (with stacked frequency allocations) which can be furnished with group frequency allocations for each direction of transmission. This type of system can be repeatered and used on cable plant and requires only one pair per system. Equipment of this type is sometimes referred to as low cost cable carrier; however, for most types, the repeaters have to be powered from 117 volts a.c., therefore, they cannot be proved in economically over 4-wire systems which power repeaters from the terminals. There is some equipment available, however, which can operate 2-wire and still power the repeaters from the end terminals over the same two wires. Although many items discussed in this section apply to 2-wire repeatered systems this section is primarily concerned with physical 4-wire systems. Figure 2 illustrates the difference between stacked and grouped frequency allocations. Figure 3 illustrates the difference between 2-wire and 4-wire carrier systems.

2.4 A significant component of any grouped frequency cable repeater is the equalizing network. Since loss through cable varies with frequency, the lower carrier frequencies are attenuated less than the higher frequencies in the same direction of transmission. Since the broadband amplifiers which are usually flat in frequency response amplify all frequencies equally, it is necessary to provide a network that attenuates the various frequencies in the reverse slope of the frequency-attenuation slope of cable. When the levels are properly equalized ahead of the amplifier, the output out of the equalizer at various frequencies will be equal before amplification and transmission toward the next repeater. Equalization for each previous cable section takes place at the repeater input and if correct at each repeater the various carrier frequencies of the system will arrive at the distant terminal at the proper level for demodulation. Thus in Figure 3, top drawing, the carrier frequency level of channel No. 1, 10 kc would be attenuated much less than the level of channel No. 22, 304 kc at the first repeater point so that the ideal equalizing network would attenuate the 10 kc signal for a specified high loss while offering little or no additional attenuation to the 304 kc signal. Therefore, as the 10 kc and the 304 kc signals enter the amplifier, their respective levels will be equal and will be amplified equally. Figure 4 shows the position of equalizers in a cable carrier repeater.

2.5 In the alignment of a cable carrier system, one of the major tasks is to move from one repeater to the next setting the equalizing networks such that the transmit levels out of each amplifier are the same throughout the band of frequencies involved. Within the past two to three years sufficient experience has been gained about the slope characteristics of plastic insulated cables of various types so that the aligning of repeaters is now familiar routine to experienced installers. Prior to this period the cable characteristics of paper insulated lead cables were well known but little was known about plastic insulated cable. Where difficulty is encountered it is usually due to the existence of some impedance irregularity in the cable pair such as a load coil, a build out capacitor or another cable pair bridged on the circuit.

2.6 Not all cable carrier systems handle equalization of levels in the manner described above. Cable carrier systems such as Western Electric "N," or its equivalent, use a different technique which accomplishes the same results. Instead of depending upon equalizing networks, the transmit output of the terminals is sloped such that the higher frequency levels are transmitted at a higher output level than the lower frequency levels. This process together with another technique called frequency frogging at each repeater enables the signals throughout the spectrum to be transmitted through the repeaters at the proper levels for the receiving terminals. The two frequency bands for send and receive are inverted in passing through the repeaters. Thus, the highest frequency channel in one line section becomes the lowest frequency channel in the succeeding line section. So nearly constant are the sums of the losses in the two sections for all channels for the frequency range chosen that the equalization is provided without resort to any major slope correction in the repeaters. Frequency frogging also helps overcome "run around" coupling at repeaters which is discussed in paragraph 5.51. Frequency frogging is further explained in REA TE & CM-901, "Fundamentals of Carrier Telephone," paragraph 11.

2.7 Aside from the relatively new innovation of the transistorized repeaters other significant differences of low cost cable carrier as compared with open wire carriers are:

2.71 A number of new systems have a capacity of up to 24 channels per system. There is much common equipment in these systems which is an important factor in the lower cost.

2.72 When the terminals as well as the repeaters are transistorized, the current drain, or power consumed, including power for the repeaters from each end terminal is significantly lower than for tube type carrier. This permits powering the equipment from the 48-volt central office supply and eliminates costly 48-volt d.c. to 130-volt d.c. converters or 130-volt banks of batteries as part of the standby facilities.

2.73 Where the terminals are transistorized the equipment is very compact resulting in considerable savings of office space. This is an important factor in overall savings.

2.74 Since repeaters on 4-wire systems are low cost, it is advantageous from a crosstalk standpoint to make them low gain devices ranging from 20 to 25 db per repeater section. For exchange grade cables the repeater spacing for most of the low cost systems ranges up to almost two miles for 19 gauge to 1.4 miles for 22 gauge.

2.75 Most equipment is usually installed without compandors or other crosstalk reducing devices to keep costs low. Most cable carrier equipment can be optionally equipped with compandors or other crosstalk reduction devices if needed. Compandors reduce the effect of noise on the carriers and relax the crosstalk coupling loss requirements between cable pairs when more than one carrier system is installed within a cable. Compandors are discussed in TE & CM-901, "Fundamentals of Carrier Telephone," paragraph 10.

2.76 Crosstalk advantage usually obtained by using compandors on amplitude modulated carrier is inherent in some equipment using angular modulation techniques. Eighteen db or more crosstalk advantage is possible with wide deviation angular modulated carrier and in effect compandor advantage is provided at no extra cost.

2.77 On some carrier equipment the test tone level at 1000 cycles per second is less than the conventional "O" dbm. Although it may introduce some inconveniences in testing levels, the reduced test tone levels, (-10 dbm or so) are more in keeping with actual speech powers encountered in normal conversations.

2.78 Costs vary from one-third to one-half the cost of single sideband open wire equipment when systems are fully equipped to capacity.

2.79 If repeaters are powered from the terminals the physicals cannot be used for voice circuits.

3. SIGNALING OPTIONS AVAILABLE ON CABLE CARRIER SYSTEMS

3.1 As indicated previously, trunk carrier and subscriber carrier equipment are almost identical except for the signaling options. Some manufacturers have made equipment such that it can be readily converted from trunk to subscriber use or vice versa merely by changing out the signaling cards.

3.2 The majority of the cable carrier systems available today signal from one terminal to the other with inband or out-of-band signaling tones (for example 3700 cps) at voice frequencies. These tones are modulated into carrier frequencies and the signaling information passes through terminals and repeaters in the same way voice frequencies are transmitted. REA TE & CM-901 covers this in paragraph 13. One type of low cost cable carrier equipment utilizes time division modulation for signaling, however, which may be the start of a new trend.

3.3 Whether the carrier signaling is inband, out-of-band, or time division equipment, the most common options for connecting to central office equipment can be classified as follows:

a. E & M for trunks.

b. One-way loop dial for trunks.

c. Subscriber carrier for exchange plant.

d. Foreign exchange service.

3.4 E & M Signaling

3.41 E & M signaling is covered quite thoroughly in REA TE & CM-319, "Interoffice Trunking and Signaling," and as far as carrier equipment is concerned it means that if a COE trunk circuit has T, R, E & M leads such leads can be connected to T, R, E & M leads of a carrier terminal and signaling is possible between terminals on this basis. A terminal originating signaling towards a distant terminal accomplishes it by placing battery on its "M" lead for seizure and alternately applying battery and ground corresponding to the dial pulses being sent. This action usually results in a ground being placed on the "E" lead and alternately applies ground and open conditions corresponding to the dial pulsing at the opposite terminal. Return supervision is usually accomplished by applying battery to the distant terminal "M" lead which results in ground being placed on the originating "E" lead. Where the trunks are two-way, operation signaling can be accomplished in either direction. After the signaling information is sent to the carrier terminal by its "M" lead it depends on the particular carrier system as to whether inband, out-of-band or time division signaling is employed between terminals.

3.42 In every case where E & M signaling is specified, the central office equipment provides an E & M trunk circuit to convert loop type signaling from the subscribers plant (opening and closing a d-c loop path) to "M" lead signals and respond to "E" lead signals.

3.43 Since about 1960 the Bell System has been specifying so called "E" type signaling equipment for some carrier systems. "E" type signaling equipment denotes inband signaling through carrier equipment using a single frequency, usually 2600 cycles per second. This type signaling is also referred to as "SF" signaling. Since carrier is effectively equivalent to a 4-wire circuit identical 2600 cps tones can be used in opposite directions for signaling. At this time "SF" signaling is usually on an "E & M" or loop dial basis. Just as explained above, when E & M signaling is specified an E & M trunk circuit is required of the central office equipment bringing out T, R, E & M leads for connections to the "SF" signaling unit. The "SF" unit takes the "M" lead signals and transmits them from one carrier terminal to the other using interrupted inband 2600 cps tones.

3.44 "SF" signaling equipment is also available for one-way loop dial signaling through the carrier. Therefore, in discussing "SF" signaling it is also necessary to know whether it is E & M or some form of loop dial signaling.

3.45 "SF" signaling equipment at this time is not an inherent part of any carrier equipment. Usually this equipment is mounted separately from the carrier equipment. Figure 5 shows the equipment arrangement where "SF" equipment is used for E & M signaling.

3.46 Independent telephone equipment manufacturers can now furnish "SF" equipment which is compatible with Western Electric "E" type equipment at the opposite end. Usually the hybrid circuit is an inherent part of the "SF" equipment and the only connection to the carrier equipment is to the "mod in" and "demod out" points known as the 4-wire voice frequency points.

3.47 Figure 5 is a simplified block diagram of a trunk employing "SF" inband signaling. The transmission path between terminals must either be a carrier derived channel or a 4-wire physical in this example since the same frequency (2600 cps) is used for signaling in both directions. On 2-wire circuits employing inband signaling, two different frequencies such as 2600 cps and 2400 cps are used for signaling in opposite directions. The functions and features of these units are essentially the same as those described below for the 2600 cps units. Information from the switching equipment in the form of d.c. pulses or on-hook and off-hook signals appearing on the "M" lead determines whether the 2600 cps signal is applied to or removed from the transmitter. To avoid the obvious conflict with speech signals, the tone is on in the idle or on-hook condition ("M" lead grounded). In the off-hook condition battery is applied to the "M" lead which in turn removes the 2600 cps from the transmitter. When the "M" lead is pulsed the tone is alternately applied and removed from the transmitter. The path to the office side of the equipment is opened simultaneously with the application of tone. This prevents noise which might be present at the drop side of the equipment from interfering with the control signals and also keeps the 2600 cps tone from reaching the calling party. One refinement that is not indicated on Figure 5 is a signal tone level control. The 2600 cps signal is normally applied to the line about 20 db below test tone during the idle (on-hook) condition. During a dial pulse sequence and the first 100-200 milliseconds of steady tone-on, the level is increased approximately 12 db to improve the signal-to-noise ratio and therefore the dialing reliability. In the receiver of the unit the incoming signal from the far-end is divided between the talking path and the signaling path. The presence of a 2600 cps tone of adequate level in the signaling path causes the signal switch to insert a filter into the talking path which prevents the 2600 cps signal from reaching the drop side of the equipment. In order to prevent the degradation of speech signals, this filter is switched out of the talking path when the far-end indicates an off-hook condition (tone off). During certain connections such as those to an intercept operator, the far-end does not indicate an off-hook condition and the filter remains in the talking path and prevents some speech energy from reaching the calling party. This condition is necessary however in order that certain calls are not billed. The signal switch also controls the state of the "E" lead. When tone is received from the far-end the "E" lead is opened and in the absence of tone the "E" lead is grounded. The most difficult feat that the inband feature imposes on the receiver is that speech energy at the signaling frequency must be prevented from causing false off-hook conditions, or "talk down." This is the purpose of the guard network shown in Figure 5. All of the speech energy except that occurring at 2600 cps is accepted and rectified by the guard network and fed to the signal switch in the form of a d.c. control voltage. Any energy at 2600 cps passes through the band pass filter, is also rectified and fed to the signal switch. The guard voltage opposes the rectified 2600 cps signal and prevents the signal switch from opening the "E" lead.

3.5 One-Way Loop Dial Signaling

3.51 One-way loop dial signaling options have found increased application with low cost cable carrier systems where one-way trunks are economical. Connection of a one-way loop dial carrier channel to central office equipment is usually made with tip, ring and sleeve leads. In other words, a subscriber loop connected to a loop dial carrier channel (after the central office has switched the subscriber line to the carrier channels) can furnish loop signaling (open and closed d.c. pulses) to the carrier, and the carrier equipment at the opposite terminal will present to the central office equipment incoming selector the same open and closed loop conditions. There is no need for a central office equipment trunk circuit since in effect the carrier contains the trunk circuit. One-way loop dial signaling means that a given channel will handle telephone traffic in one direction only and that dialing can take place in one direction only. The carrier channel will provide talking battery to the subscriber loop once it is connected to it by means of the central office equipment. As stated in paragraph 3.41 for E & M signaling, once the signaling intelligence on a loop basis is accepted by the carrier terminal it depends on the method chosen by the carrier manufacturer as to how it is transmitted through the system at carrier frequencies. It can be by means of out-of-band, inband voice frequency tones or by other means such as time division modulation.

3.52 The signaling cards on circuits of one-way loop dial carrier channels are different at each end. The outgoing loop dial signaling circuit contains the battery feed relay explained above and signaling, always originates from the outgoing terminal. The outgoing carrier channel terminal is usually connected directly to levels of outgoing selectors of the central office equipment. At the other end the incoming carrier channel terminal is usually connected directly to an incoming trunk selector. The circuitry of the incoming signaling card will present open and closed conditions through a

nominal value resistor to the incoming trunk selector. The incoming carrier channel terminal is able to detect reverse battery and return answer supervision to the originating terminal for the benefit of calls originated by paystations. One-way loop dial carrier circuits are analogous to 2-wire physical circuits using one-way loop dial signaling except that the outgoing impulse repeater is not required. There are limitations with respect to dial pulse distortion as to the length of subscriber loops which may be connected to one-way loop dial carrier channels, however, loops up to 1500 ohms including the telephone instrument are possible with most equipment. Longer loops will have long line adapters connected to them.

3.53 The advantage of using one-way loop dial carrier trunks over conventional E & M circuits is in the savings made in COE trunk circuits. The net saving has been found to be as much as $260 per circuit since there is no need to use two E & M trunk circuits (one at each end) in the COE. The cost of one-way loop dial carrier channels is about the same as E & M carrier channels. Of course when only one-way dialing trunks are used more trunks may have to be specified over all, but nevertheless considerable savings are possible. One-way loop dial signaling should be considered where a large number of trunks are to be provided. Figure 6 shows how one-way loop carrier is connected to central office equipment.

3.6 Subscriber Carrier Signaling

3.61 Subscriber signaling circuitry on presently available cable carrier systems is identical in principle to the subscriber signaling used for many years on open wire subscriber carrier. This subject is covered in TE & CM-901, paragraphs 13 and 14. Subscriber cable carrier systems are available which can accommodate almost all possible kinds of service from a switchboard, such as ten-party divided ringing, bridged ringing and superimposed ringing. For one and two-party service at this time, signaling circuitry would have to be bought which has the capability of ten-party divided ringing; however, it can be used for one, two or four-party line ringing.

3.62 When the telephone industry shows a demand for only one, two or four-party line ringing, future systems will probably be provided with signaling circuitry at reduced prices from ten-party ringing since the complex circuitry required for ten-party full selective ringing would be unnecessary.

3.7 FX, Foreign Exchange Signaling

3.71 This type of signaling circuitry is usually used with trunk cable carrier systems where one or more channels may be used to provide foreign exchange service for certain subscribers from one exchange into another. FX signaling is identical to subscriber carrier signaling except that the subscriber terminal is not usually equipped with circuitry to generate ringing power. Since the subscriber terminal is usually mounted in a central office together with the rest of the trunk carrier channels, central office ringing power is used to signal out on a subscriber loop. This type of carrier signaling may also find some application where wide area telephone service (WATS) is provided and it is necessary to extend the subscriber loop all the way to a properly equipped office for connection to the network. Part of a WATS circuit may be easily provided over spare channels of a cable carrier system equipped with FX signaling. With the increased demand for DTWX, (dial teleptypewriter service) foreign exchange signaling carrier equipment can be used to reach properly equipped office which handle DTWX switching.

4. ELECTRICAL PROTECTION OF TRANSISTORIZED EQUIPMENT

4.1 With the use of transistorized d.c. powered carrier repeaters installed along cable routes, came some problems in protecting their circuitry from lightning surges induced in the cable pairs since most transistors cannot withstand voltage surges in excess of about 100 volts. Since carbon blocks operate at a minimum of about 300 volts, they are obviously inadequate for the protection of transistors which are exposed to outside plant surges. Most manufacturers now recognize this and supplement carbon block protection with internal low voltage protection where such protection is needed. Protection of the terminal equipment is not as critical as the repeaters since the transistorized circuitry is protected from outside plant surges by impedance matching transformers, filters, etc. This deficiency in protection from lightning which appeared in some of the early cable carrier systems has been corrected and these systems now offer reliable service.

4.2 REA TE & CM-822, "Electrical Protection of Carrier Equipment," should be referred to for a more detailed discussion of protection requirements on cable carrier systems.

5. TRANSMISSION OF CARRIER FREQUENCIES THROUGH CABLES

5.1 As indicated previously proper carrier frequency transmission through cable requires numerous repeaters because the attenuation at carrier frequencies in cable plant is very high when compared with open wire. The higher the top frequency of a cable carrier system, the higher the attenuation. If more than one system is to operate under the same cable sheath then the possibility of crosstalk between systems also must be considered. Therefore, two characteristics of cable plant are important with respect to cable carrier systems; (1) attenuation per unit length, and (2) crosstalk coupling between the various pairs in the cable.

5.11 In application engineering of a cable carrier system the engineer has to know the type of cable over which the carrier will operate. It is desirable to know as accurately as possible the attenuation per unit length since spacing of the repeaters has to be calculated. The attenuation per unit length of cables used in the industry varies widely depending on gauge, mutual capacitance, whether it is paper or plastic insulated, etc.

5.12 Exchange grade cable is considered "high capacity" cable with an average mutual capacity for all the pairs of .083 mfd. per mile. The deviation in capacitance among pairs may vary and values as high as .096 mfd. per mile are present on older existing cables. What is sometimes referred to as "toll grade cable" has a mutual capacity of .066 or .062 mfd. per mile. The lower the mutual capacity, the lower the attenuation at carrier frequencies. To illustrate the effect of gauge, mutual capacity, and type of insulation, the following data is given at a typical frequency of 300 kc. A comparison is also given of repeater spacing assuming 20 db gain per repeater.

	19 GAUGE PLASTIC INSULATED	19 GAUGE PAPER INSULATED	19 GAUGE PLASTIC INSULATED	22 GAUGE PLASTIC INSULATED	22 GAUGE PAPER INSULATED
	.066 mfd./mi.	.066 mfd./mi.	.083 mfd./mi.	.083 mfd./mi.	.083 mfd./mi.
ATTENUATION AT 300 KC	7.6 db/mi.	9.0 db/mi.	10.3 db/mi.	13.7 db/mi.	15.0 db/mi.
REPEATER SPACING INTERVAL PER 20 DB OF LOSS AT 300 KC	13.9 kf	11.7 kf	10.2 kf	7.7 kf	7.1 kf

It is seen from the above comparison that an application engineer has to know what kind of cable is involved in order to approximate repeater spacing.

5.13 In the interest of economy and standardization, REA specifications for new cable installations require cable in sizes of 18 pairs or more having an average mutual capacity of 0.083 ± 0.004 mfd. per mile. Cables of smaller sizes have average mutual capacity of .083 mfd. per mile but average tolerances of ± .007 ± .01 for 12-pair and 6-pair, respectively. Where cables are prescribed for use on trunks it is possible under existing REA practices to procure cable of 12 pairs and up where the mutual capacitance will be with ± .004 mfd. from .083 mfd. per mile. Although lower capacity cable means lower loss and fewer repeaters, it is not recommended that .066 mfd. per mile cable be used. Gain by means of transistorized repeaters is low in cost and in most applications means only a few additional repeaters are required with the use of standard cable types. There may be some isolated instances where .083 mfd., 19-gauge cable would provide a facility which would be beyond the transmission capability of certain cable carrier systems. Should this be the case, .066 mfd. cable could be specified but REA approval should be obtained for such a proposal, which would cost at least 10 percent or more than .083 mfd. cable. <u>The use of other than .083 mfd. cable by REA borrowers is not generally recommended.</u>

5.14 Temperature variations affect attenuation in cables. The higher the temperature the higher the attenuation. All low cost carrier systems contain automatic gain control circuitry to compensate for temperature variations normally encountered in aerial cable plant.

5.15 As discussed previously on the subject of equalizing networks, paragraph 2.4, the slope characteristic of frequency versus attenuation is important to know. Manufacturers design equalizers which have a reverse attenuation slope with respect to frequency. These designs are based on typical cable data available to them but, it is not uncommon to find cable sections which have somewhat different slopes than that for which the built in equalizer was designed. In these instances, however, there is usually enough tolerance in the equalizer strappings to permit proper adjustment of the repeater section. If the equalizers cannot be adjusted to meet the slope characteristics, the cable plant may have water in it, there may be loading coils, build out capacitors, etc., in the pairs which are selected for carrier transmission. If equalizers cannot be adjusted or strapped within certain tolerances and if they can't be adjusted to meet the slope characteristics a special network might be required or at least the repeaters would have to be spaced closer together.

5.16 Slope of cable varies with temperature changes, however, it is not so drastic a change within the operating range of low cost carrier systems that it is considered controlling. Change in slope characteristics with temperature is known as "twist." Twist regulation is usually necessary on long haul carrier systems, but, this subject is not covered in this section since such distances are rarely attained in REA borrowers' systems.

5.2 Crosstalk Between Carrier Systems

5.21 A complete treatise on carrier crosstalk is beyond the scope of this Section. Crosstalk or noise as measured on a channel includes interference from foreign sources as well as the coupling from other carrier systems in the same cable. This discussion pertains only to the disturbance from carrier channels on other pairs within the same cable.

5.22 Crosstalk from other carrier channels on other pairs in the same cable can occur because of two reasons. First, the carrier systems may not coordinate with each other with respect to frequencies and operating levels. Second, carrier frequency crosstalk coupling loss between cable pairs may be insufficient even where the systems coordinate with each other with respect to frequencies and levels.

5.3 Frequency and Level Coordination

5.31 In general, where various cable carrier systems are applied to pairs in the same cable, identical frequencies and levels must prevail among the systems. This means that for all practical purposes if a certain brand of cable carrier equipment is already in operation almost assuredly the same type of equipment or equipment which coordinates in levels and frequencies has to be added for expansion. Unfortunately, in the United States, very few of the low cost cable carrier systems which are under discussion in this section coordinate with each other or with other types of carrier. Most low cost cable carrier systems do not fully coordinate with the Western Electric "N" frequency allocation which is widely used throughout the Bell System although it is often necessary to operate carrier in the same cable with "N" systems.

5.32 There are exceptions to this generalization. There are some independent carriers available that are compatible or coordinate with "N" type equipment.

5.33 Coordination of carrier systems is also accomplished by not duplicating frequencies among systems. For example, an existing carrier system in a cable may use frequencies from 5 kc to 30 kc. A cable carrier system could be added on other pairs in this same cable which operates in a range from 50 kc to 350 kc. Usually, however, the frequencies of cable carrier systems are in the same range with each other and overlap at some portion of their spectrum.

5.34 Frequency coordination among carrier systems is a matter which is usually investigated closely by carrier application engineers. Nevertheless, in planning for the use of carrier it is worthwhile to consider carrier systems in operation already and the ability to expand facilities with other carrier equipment.

5.35 In many instances borrowers have suggested the use of low cost carrier systems for interconnection with connecting companies. The connecting companies in many instances have had to refuse the request because they have other types of carrier operating in the same cables which do not coordinate in frequency. This is a valid reason for not being able to use low cost carrier even though it could mean considerable savings in equipment costs.

5.4 Crosstalk Loss Between Cable Pairs

5.41 In the early days of cable carrier systems, carrier did not prove economical compared with voice frequency systems. Carrier frequencies of not more than 60 kc were used in order to keep the crosstalk losses between cable pairs sufficiently high in long distances (hundreds or even thousands of miles). The first long haul 4-wire cable carrier systems provided 12 channels in the frequency range of 12 to 60 kc. In order to build low cost carrier systems it was necessary to use more of the frequency spectrum and more channels per 4-wire circuit in order to reduce the cost of the carrier terminals per channel. Low cost cable carrier systems are now available with frequencies up to almost 500 kc. The crosstalk losses between cable pairs decrease rapidly with frequency and increase (improve) rapidly with reduced length. Therefore, crosstalk between cable pairs is an important consideration with both relatively low frequency long haul carrier systems and relatively high frequency low cost short haul carrier systems.

5.42 By January 1, 1964, REA cable specifications will require specified crosstalk losses between various pair combinations. It will be required that on cables of 6 pairs or larger the root mean square, RMS, value will be 71 db/kf at 150 kc. The value of 71 db/kf is the RMS crosstalk loss of adjacent pairs in the same layer, alternate pairs in the same layer and center to first layer which are considered among the worst possible pair combinations. The RMS crosstalk loss in db is the number of db corresponding to the RMS crosstalk voltage ratio. If a measuring frequency higher than 150 kc is preferred, the crosstalk loss requirements may be corrected by subtracting $20 \log_{10} \frac{\text{"X" kc}}{\text{150 kc}}$. To correct for a length other than 1000 feet subtract $10 \log_{10} \frac{\text{length in feet}}{\text{1000 feet}}$. REA cable specifications for crosstalk may change in the future but for purposes of the discussions which follows the RMS value of 71 db/kf at 150 kc will be the accepted value.

5.43 Far-end crosstalk is usually controlling with carrier systems as send and receive frequencies are different (usually staggered 8 kc or thereabouts) and near-end crosstalk is of little or no consequence. Also "run around" or near-end crosstalk is of no concern since the repeater gains are kept low.

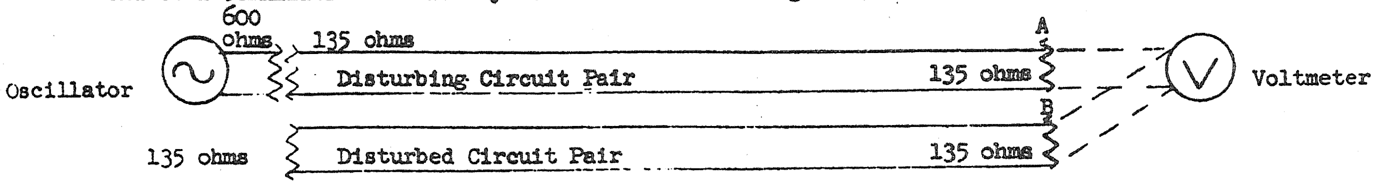
5.44 As is noted above in the crosstalk requirements, provision is made for calculating expected far-end crosstalk losses at various distances and at various frequencies above 150 kc. The meaning of RMS (root mean square) crosstalk loss which is given in db requires some explanation as to what it means in practical applications. The "RMS db" is actually the db corresponding to the RMS crosstalk voltage ratio. A ratio of .001 corresponds to 60 db ($-20 \log_{10} .001$). The RMS db rather than the minimum db is used since the "RMS db" may be readily extrapolated from one splicing length to many such lengths in series. If the "RMS db" for the long length is known it is improbable that the lowest crosstalk loss between any pair combination in the long length will be more than 10 db below the "RMS db" for this length. Or, another way of saying it is that the great majority of the pair combinations will have a crosstalk loss greater than 71 db.

5.45 For example, suppose a 12 pair cable which meets REA crosstalk requirements is to be used for three cable carrier systems. Calculations for the distance and frequencies involved indicate that if pair combinations in one splicing length have 71 db crosstalk loss in 1000 feet at 150 kc satisfactory multisystem carrier operation can be expected. For three systems a total of six pairs of the 12 pair cable would be used for carrier and it is likely that any six pairs could be used without resorting to selecting pairs to have high (good) crosstalk losses. Of the six pairs remaining chances are also very good that pair combinations involving these pairs are adequate from a crosstalk loss standpoint and probably one or maybe two pair combinations would not be suitable for carrier application. As indicated above an RMS value does not provide too much deviation either in the number of pairs or in the value below the RMS value. Also in a three system carrier installation it is wise to have some extra cable pairs available in the event something happens to the carrier pairs in use. Many manufacturers recommend that standby repeatered cable pairs be in operation in the event of failure of the repeatered cable pairs or any of the repeaters, the standby facilities can be switched over for use.

5.46 Crosstalk coupling varies with frequency and length of paralleling systems. The higher the frequency and/or the longer the distance between terminals the worse (lower) the crosstalk loss due to far-end crosstalk coupling. The form of crosstalk coupling between paralleling cable pairs which is known as transverse far-end coupling usually control and it is independent of the number of repeaters between terminals. To overcome the effect of transverse far-end crosstalk, electronic devices such as compandors are used for its reduction. Also, by using wide swing angular modulated carrier (sometimes referred to as frequency modulation) about the same inherent crosstalk advantage is obtained as with compandors at no additional cost. Compandors give an approximate crosstalk advantage

of 22 db while angular modulated carrier of the type used in low cost cable carrier systems inherently give 18 db or better crosstalk advantage. Obviously the number of repeaters used influences noise and other forms of crosstalk coupling. This is discussed in paragraph 5.5.

5.47 Far-end crosstalk, or the effect of a disturbing circuit on a disturbed circuit at the receiving end of a termination is usually measured in short length of from 1000 feet to 5000 feet as follows:



The far-end measurement of crosstalk is the ratio of the voltage across the receive termination "A" to the voltage as read across receive termination "B." As an example, if in the above measurement the voltmeter across "A" read 1 volt, the reading at "B" would be very small in the order of .000282 volts. This ratio corresponds to 71 db ($-20 \log_{10} .000282$). The range of most commonly available voltmeters is about 100 db so it is seen that for the above distances the limit of instruments is approached. If the cable lengths measured were longer, the receive level at "A" would be down by the amount of the attenuation from the location of the oscillator and the loss at point "B" would be correspondingly lower by the amount of the coupling loss between the pairs. Therefore, it is not possible to measure crosstalk (or attenuation) over the entire length of a cable carrier system facility as is customarily done for open wire carrier systems. The instruments usually used for crosstalk measurements include a constant impedance oscillator, 600 ohms, over a frequency range from 1 kc to 500 kc, accessories for proper impedance transformation to cable impedances, terminations, and a selective frequency voltmeter. To obtain the RMS value of pair combinations for a cable, obviously many pair combinations have to be measured and the root mean square value calculated. In the future REA will publish testing procedures for measuring cable parameters for complience to REA cable specifications which will cover more thoroughly the measurement procedure.

5.5 Crosstalk Due to Numerous Repeaters

5.51 Another source of crosstalk between systems is known as interaction or "run around" crosstalk which is from the output of a repeater into the input of another repeater of another system usually by means of another pair. In a multisystem carrier application where repeaters for all the systems terminate in the same repeater housing and one cable is used for both send and receive frequencies, it is possible that the coupling from a cable pair to a nonrepeatered "tertiary circuit" is strong enough so that the output of an east-bound repeater can couple to a tertiary circuit and then back again into another cable pair which feeds into the input of an east-bound repeater of another system located in the same cabinet or adjacent repeater cabinets. This "run around" coupling increases with higher frequencies and is affected by the repeater gain. Therefore, high gain and high frequencies can make "run around" coupling intolerable. High gain repeaters may reduce the number of repeaters and thus help the "run around" affect, but, the reduction can be negated by the increased gain. On extremely long cable carrier systems with high gain repeaters, 60 db or 70 db, the "run around" affect would have been intolerable with single cable therefore separate cables are used for opposite directions of transmission. Frequency frogging minimizes the "run around" affect. With frequency frogging repeaters the two frequency bands for each direction of transmission are inverted at each repeater such that in a one-way direction the output frequencies from a repeater are not the same as the input frequencies, therefore, the "run around" affect is minimized. Low cost cable carrier systems employ low gain repeaters, 20 to 25 db gain and therefore "run around" coupling is not a serious factor. Also the range of the carrier system is short. The longer range carriers such as the Western Electric "N" type or equivalent employ higher gain repeaters, 40-45 db gain, however, frequency frogging at each repeater section minimizes "run around" coupling affects.

5.52 The importance of near-end crosstalk coupling is minimized for frequency division types of carrier systems by staggering the carrier frequencies of oppositely directed one-way channels by 8 to 10 kc. This makes the near-end crosstalk coupling out of band. The impedances which the carrier terminals and carrier repeaters present to the cable pairs are a reasonable match with the carrier frequency characteristic impedances of the cable pairs (about 110 to 135 ohm resistance). These impedance matches prevent near-end crosstalk coupling from being reflected to the far-end of the carrier system where it would become a component of the far-end crosstalk coupling.

5.6 Distance Limitations of Carrier Systems

5.61 In the foregoing paragraphs various factors were discussed which limit the range of cable carrier systems. Of all the factors presented, two of them are the most critical for the low cost cable carrier systems now available and these factors dictate the maximum range of some systems. The factors are:

a. Limitations on the number of repeaters which can be powered from terminals.

b. Equal level far-end crosstalk coupling where carrier is proposed which does not contain compandors, sonads, or other inherent characteristics which liberalizes crosstalk loss requirements between cable pairs. Of course where one system of cable carrier is all that is required crosstalk is not a problem. On rural system applications where up to 24 channels can be derived from one system and the initial trunking needs are somewhat below 24 channels there is no concern about crosstalk until the 25 channel is required.

5.62 Usually the total number of repeaters is limited by the number of repeaters which can be conveniently powered from each terminal rather than by the equal level far-end crosstalk coupling. Therefore, low cost cable carrier systems are limited by repeater power design criteria to around 25 miles. Of course if intermediate powered repeater points are installed and more repeaters can be added, the transverse far-end crosstalk coupling becomes controlling on multisystem carrier applications.

5.63 With respect to Western Electric type "N" carrier or other equivalent carrier systems the distance limitations of such equipment is around 200 miles. The various limitations discussed above would apply to this type equipment, however, the "N" type is designed to overcome these limitations. With respect to far-end crosstalk coupling the distance limitation is extended due to the use of compandors, frequency frogging repeaters, and the fact that the top frequency of the system is held to 256 kc. Because of the frequency frogging, far-end crosstalk can be estimated on the basis of 165 kc which further extends the distance limitations with respect to far-end crosstalk. In most "N" carrier applications in the past where electronic tube type repeaters were used it was necessary to utilize commercial power with standby arrangements at a number of repeater locations along route. Transistor type repeaters are now being used where it is possible to power up to three or more repeaters from a terminal or to power as many as three or more repeaters from each side of a 117 volt a.c. powered repeater point by means of simplexed cable pairs which are also used for carrier frequencies.

5.64 All of the above features of the "N" type equipment make it a substantially more expensive carrier system than the low cost carriers, however, it is a 200 mile carrier system and it is necessary for it to have these features.

5.65 In designing trunk routes where keeping costs low is of prime importance, there is a proper application for low cost cable carrier if the distance is under 25 miles. Where this distance limitation is exceeded appreciably "N" type equipment or its equivalent should be considered.

5.66 The following three examples will serve to illustrate how to calculate whether end crosstalk is controlling. To help in this determination two curves are plotted as shown in Figures 7 and 8. As seen in the formulas these curves represent, they show the reduction in crosstalk loss as frequency increases and as length increases. This is a plot of the two formulas given in REA cable crosstalk loss requirements to correct specified values given in db/kf at 150 kc to various values of length and frequencies.

5.7 Example No. 1

5.71 To provide trunks it is planned to ultimately use three amplitude modulated carrier systems to derive 72 channels over cable facilities 24 miles long. Three systems of 24 channels each would provide the required number. It is planned that the facility will be 19 gauge buried cable meeting REA plastic insulated cable specifications. This means that the average mutual capacitance is .083 mfd. per mile and that the RMS far-end crosstalk value is 71 db/kf at 150 kc. One type of carrier under consideration can provide 24 channels using a top frequency of 480 kc. Compandors are optional with this equipment. The manufacturer specifies that without compandors a 60 db far-end crosstalk loss is required at the receive terminal. With compandors the loss can be reduced to about 40 db. With standard power options, up to 14 repeaters of 25 db of gain per repeater can be powered over 19 gauge cable.

QUESTION 1: Are compandors necessary for this application?

QUESTION 2: Would a 12 pair 19 gauge cable complement be large enough in a composite cable?

QUESTION 3: What is the total attenuation of the entire cable path from terminal to terminal?

QUESTION 4: Can this carrier equipment be used in this application?

5.72 Answer to Question No. 1

5.721 In order to answer question 1 it has to be determined if cable with the capability of providing an RMS value of 71 db far-end crosstalk loss per 1000 feet at 150 kc can be used for a distance of 24 miles at a frequency of 480 kc.

5.722 From Figure 7 it is determined that to adjust the RMS cable crosstalk loss from 150 kc to 480 kc the reduction is 10 db. Subtracting 10 db from 71 db adjusts the cable crosstalk RMS value to 61 db at 480 kc/kf. A further adjustment for 24 miles of cable length is required and from Figure 8 it is seen that the db reduction over this distance is 21 db. Subtracting 21 db from 61 db leaves 40 db at 480 kc for 24 miles as the expected RMS far-end crosstalk loss.

5.723 If at least 60 db of far-end crosstalk loss is required without compandors it is evident compandors are required. A calculated figure of 40 db at 480 kc for 24 miles is the manufacturer's 40 db minimum requirement with compandors.

5.73 Answer to Question No. 2

5.731 Since the minimum permissible far-end crosstalk loss per unit length is 40 db at 480 kc for 24 miles which translates to 71 db at 150 kc per kf it is evident the 71 db value has to be achieved on most pair combinations. Since 6 pairs are required for three systems it is most probable that 6 pair combinations meeting the 71 db RMS value can be obtained without having to select pairs.

5.732 A 12 pair 19 gauge complement in the composite cable should be satisfactory.

5.74 Answer to Question No. 3

5.741 The total attenuation for this carrier facility at a top frequency of 480 kc is calculated as follows:

5.742 From Figure No. 1 of TE & CM-406, Addendum No. 2, "Attenuation Data," it is determined that at 480 kc the cable attenuation per unit length for 19 gauge .083 uf cable at 68°F is about 12.8 db/mile. For 24 miles at 12.8 db/mile the total attenuation is 307 db.

5.75 Answer to Question No. 4

5.751 Although far-end crosstalk loss is not controlling a check is made if all repeaters can be powered from the two end terminals. It is determined that by using 12 repeaters it is possible to span 13 sections of 25 db each for a total loss of 325 db. The total attenuation is 307 db which is within this figure. In an actual application the manufacturer would probably recommend that those repeaters adjacent to central offices be spaced closer to the carrier terminals to reduce switching noise from the COE. Therefore, 13 repeaters would probably be installed.

5.752 This carrier system could be used in this application.

5.76 Discussion of Example No. 1

5.761 This example serves to show the maximum length limitations for amplitude modulated carrier on a cable with a 71 db RMS far-end crosstalk loss which operates at 480 kc. It is evident that cable crosstalk margin is reduced severely because of the high operating frequency of 480 kc. Compandors are an absolute necessity on this application.

5.762 No doubt if three carrier systems were to be applied to a cable of 50 pairs or more, the chances are very good that by selecting pairs that the three systems could be installed without compandors. Of course if only one system would be required, 24 channels, no compandors would be installed initially since there would be no other system which would cause crosstalk. There

is also a good possibility that by pair selection the second system could be added without compandors. It is only when three or more systems are operating in the same cable that good pair combinations become more difficult to select. Since the carrier requirements of most REA systems seldom exceed 24 or 48 channels, compandors would actually very seldom be required unless they were needed to suppress unwanted foreign frequency interference such as that caused by high powered radio stations whose operating frequencies fall into the range of the carrier system frequency allocation. Even then compandors might only be required only on certain channels within the system.

5.8 Example No. 2

5.81 To provide service to a group of isolated subscribers located as far as 50 miles from the central office the use of subscriber carrier is being investigated. Buried cable facilities would be installed with cable which meets REA crosstalk requirements. Approximately 40 channels of subscriber cable carrier are needed and it is desired to use a 6 pair 19 gauge cable for a substantial portion of the route. It would be possible to locate the subscriber terminal 40 miles from the central office and serve the subscribers from this point with conventional physical voice frequency circuits connected to the subscriber terminal. One possible type of carrier which could be used is an angular modulated system which can provide up to 20 channels per system. The manufacturer states that far-end crosstalk loss at the receive terminal should not be less than 40 db. The manufacturer further states that up to 12 repeaters with 20 db gain each can be installed between the two terminals of the subscriber equipment. The top frequency of the 20 channel system is 340 kc. Maximum subscriber loop limits beyond the subscriber terminal are 1200 ohms excluding the telephone set.

QUESTION 1: Can a 6 pair 19 gauge cable provide adequate crosstalk loss between pairs over a distance of 40 miles to enable the operation of two systems of subscriber cable carrier?

QUESTION 2: What is the total attenuation of the entire cable path from terminal to terminal?

QUESTION 3: Could this equipment be used in this type of application?

5.82 Answer to Question No. 1

5.821 In order to answer question No. 1 it has to be determined if a 6 pair cable with the capability of providing an RMS value of 71 db of far-end crosstalk loss per 1000 feet at 150 kc can be used for a distance of 40 miles at a frequency of 340 kc.

5.822 From Figure 7 it is determined that to adjust the RMS cable crosstalk loss from 150 kc to 340 kc that the reduction is 7.3 db. Subtracting 7.3 from 71 db adjusts the cable crosstalk value to 63.7 db at 340 kc/kf. A further adjustment for 40 miles of cable length is required and from Figure 8 it is seen that the reduction over this distance is 23 db. Subtracting 23 db from 63.7 db leaves 40.7 db at 340 kc for 40 miles as the expected far-end crosstalk loss.

5.823 Since the calculated figure of 40.7 db is within the 40 db far-end crosstalk loss specified by the manufacturer, a 6 pair cable could be used.

5.83 Answer to Question No. 2

5.831 The total attenuation for this carrier facility at 340 kc is calculated as follows: From Figure 1 of TE & CM-406, Addendum No. 2, it is determined that at 340 kc the cable attenuation per unit length for 19 gauge .083 uf cable at 60°F is about 11 db/mi. For 40 miles at 11 db/mi. the total attenuation is 440 db. Since 440 db is too much loss for 12 repeaters of 20 db gain each the use of lower loss cable such as .066 uf/mi. cable should be investigated.

5.832 From Figure 2 of REA TE & CM-406, Addendum No. 2, it is determined that at 340 kc the cable attenuation per unit length for 19 gauge .066 mfd. cable at 60°F is about 8 db/mi. For 40 miles at 8 db/mi. the total attenuation is 320 db. This is still too long for twelve 20 db repeaters.

5.84 Answer to Question No. 3

5.841 In this application, far-end crosstalk is not controlling but the overall attenuation and the ability to feed repeaters from the two end terminals are the limiting factors. By using 19 gauge .083 mfd. cable about 21 repeaters spaced 20 db apart would be needed. By using 19-gauge .066 mfd. cable 16 repeaters spaced 20 db apart would be needed. Obviously the more repeaters used in a system the more chance there is of additional noise being introduced, or the overall reliability could be

reduced because more electronic devices are in the circuit. It would be recommended that in an unusual application such as this that .066 mfd. cable be used. The .066 mfd. per mile cable would have to meet crosstalk requirements for .083 mfd. per mile cable under REA requirements. Such cable would probably have to be ordered special.

5.842 Whether 16 repeaters could be powered from the end terminals remains to be determined by the manufacturer. Higher operating voltages than usual would have to be provided but there is a possibility 16 repeaters might be powered from the end terminals. An alternative would be to establish a 117-volt a.c. power point with standby batteries some where along the 40 mile route and feed a number of repeaters on each side of this point.

5.843 The introduction of four more repeaters than the manufacturer recommends should not raise the per channel noise figure appreciably. Sixteen repeaters instead of 12 repeaters could probably be used with this equipment. Nevertheless, the manufacturers' recommendations should be obtained in any such situation where the published transmission or other limits are exceeded.

5.844 Since the furthest subscriber would be located an additional 10 miles from the subscriber terminal it can be served by conventional loaded cable voice frequency circuits as described in TE & CM-424, "Design of Subscriber Loop Plant."

5.85 Discussion of this Example

5.851 This example when compared to example 1 serve to show how the length between terminals can be extended when the operating frequency is reduced. This gain in margin by reducing frequency is advantageous because many more miles can be added in length by having a few spare db as seen in Figure 8. The lower operating frequency in this case is the reason why this carrier system could be extended with respect to far-end crosstalk.

5.852 Another point which merits discussion is that this is an angular modulated carrier and that because of it a far-end crosstalk requirement of 40 db is only required. In other words, it has an inherent advantage similar to that provided by compandors. No compandors are necessary with this equipment.

5.853 The application situation depicted in this example serves to show the distances at which carrie might be employed with cable plant should it be necessary to do so. Subscribers located 50 miles from a central office could not be served very economically by means of physical type plant. By using carrier over cable facilities extremely quiet low loss circuits are possible well beyond the range of physical type plant. Application of cable carrier as illustrated in this example might well be the method to improve existing open wire subscriber carrier installations which are long in length and which are impaired by frost or ice formation on the open wire conductors.

5.9 Example No. 3

5.91 Various methods are under consideration for providing additional toll connecting trunks from one office to another located 100 miles apart. Western Electric "N" Carrier or its equivalent is under consideration. Forty-eight channels are required, or four systems. The connecting company plans to install the carrier on its existing plant and the REA borrower plans to install new cables for the carrier for a distance of 50 miles. In a connecting company meeting the question was raised if the borrowers' cables would permit the operation of four systems in a 25 pair cable which will be the minimum size of cable along the borrower's portion of the route. Western Electric "N" equipment or its equivalent requires at least 40 db far-end crosstalk loss between systems.

QUESTION 1: Would cables meeting REA standards be satisfactory for this carrier application with respect to far-end crosstalk?

QUESTION 2: With respect to far-end crosstalk loss what would be the maximum distance possible using REA cables?

5.92 Answer to Question No. 1

5.921 REA cables provide an RMS far-end crosstalk loss of 71 db at 150 kc. To answer this question it is necessary to translate this figure to 165 kc at a distance of 100 miles. As stated previously in this section, paragraph 5.63, far-end crosstalk calculations for "N" type carrier which employs frequency frogging at repeaters can be computed using a frequency of 165 kc even though the highest frequency used is 256 kc.

5.922 From Figure 7 it is determined that to adjust the RMS cable crosstalk loss for 150 kc to 165 kc/kf that the reduction is almost negligible or about 0.8 db. Subtracting .8 db from 71 db adjusts the cable crosstalk RMS average to 70.2 db at 165 kc/kf. A further adjustment for 100 miles of cable length is required and from Figure 8 it is seen that the db reduction is 27.2 db. Subtracting 27.2 db from 70.2 db leaves 43 db at 165 kc for 100 miles as the expected far-end crosstalk loss.

5.923 Cable which meets REA standards is satisfactory for this application.

5.93 Answer to Question No. 2

5.931 Working in a reverse procedure starting with 71 db at 150 kc per kf if the 165 kc frequency requirement would only degrade the far-end crosstalk loss by 0.8 db to 70.2 db at 165 kc/kf and if 40 db is the absolute minimum requirement then there is a margin of 30.2 db left which can be applied to distance.

5.932 Referring to Figure 8 and looking along the ordinate of the curve to 30.2 db we see that approximately 200 miles would be the maximum allowable distance.

5.94 Discussion of Example 3

5.941 This example shows how much further carrier can operate in the same cable when the frequency is kept low and frequency frogging repeaters are used. This shows up quite readily in reviewing the reduction values for Example 1 and 2 where the frequencies involved were 480 kc and 340 kc, respectively. In other words in applying a cable carrier system, more channels, which require higher operating frequencies are traded for shorter distance operation. Low cost cable carriers as covered herein have a definite place in supplying many of the trunk and subscriber carrier channels where extending long distances such as that given in this example are not required.

6. APPLICATION ON AERIAL CABLE

6.1 Cable carrier finds much application on aerial cable especially where it is added to existing cable. About the only difference in engineering low cost carrier for aerial plant versus buried plant is consideration of temperature swings. Temperature swings throughout the country may vary from as low as -40°F to +110°F ambient temperature. Equipment does not usually have to regulate for losses at these two extremes but instead from a mean value. For example, if the mean temperature is 50°F, it can get as hot as 110°F or as low as -10°F and the carrier should be able to regulate for temperature changes ± 60° from a mean 50° temperature.

6.2 Referring to Figure 1 of REA TE & CM-406, "Attenuation Data," the temperature swing between 0°F and 140°F is reviewed from the given data for 19 gauge .083 mfd. plastic insulated cable.

Temperature	Attenuation in db/mi at 480 kc 19 gauge .083 mfd. cable	Attenuation for 20 mile cable facility	Change due to temperature from 80°F
0°F	12.0 db/mi	240 db	-24 db
80°F	13.2 db/mi	264 db	—
140°F	13.8 db/mi	276 db	+12 db

The above variation in carrier frequency attenuation due to temperature is accounted for by means of regulation circuits which are built into carrier terminals and in some carrier repeaters. Methods of regulations vary among carrier manufacturers. Some carrier systems install regulated repeaters at certain intervals along the cable to compensate for the attenuation change with temperature. The channel terminals also contain regulation circuitry. Other carrier systems do not have regulated repeaters but may vary the repeater feed current with temperature changes in the simplex loop to obtain some regulation in all the repeaters while most of the regulation is contained at the receive terminal of the equipment.

6.3 If the specifications for carrier systems are examined the regulation may be given in terms of the variation in the number of db at voice frequencies (± .5 db to ± 1.0 db) for carrier frequency line variation of a change of number of db (± 5 db to ± 8 db from a nominal receive carrier level). Where regulated repeaters are employed, the repeaters are spaced so that the carrier frequency levels are within the regulation range with expected temperature variations.

6.4 Occasionally it may develop that cable carrier might be considered for application to rural distribution wire. RDW of the older design which does not have an outer plastic jacket would be very susceptible to wide variations in transmission characteristics due to wet weather, ice, and sleet conditions. These conditions on RDW of this type severely change slope and attenuation characteristics beyond the capability of most carrier systems. RDW of this type should not be used as a path for cable carrier or for any kind of carrier.

6.5 A new and improved type of RDW which contains an outer jacket of plastic around the pairs is now on REA's Acceptable List of Materials. This type of RDW is almost identical to regular cable except that it does not contain a copper or aluminum shield around the pairs. The slope and attenuation characteristics of this type of RDW are much improved over the older type and approach the characteristics of regular shielded cable. While this type RDW may be satisfactory from a slope and attenuation standpoint it still does not contain a shield which is very important in isolating carrier systems from foreign interfering frequencies. Where new construction of outside plant is involved in the installation of a cable carrier system, shield cable should always be provided. The cost difference between the two types of facilities is not so great that it is worthwhile risking the successful operation of carrier equipment which is a sizeable investment.

6.6 Interference from foreign frequencies is a factor to be considered in applying cable carrier, particularly if past experience in the area has shown certain frequencies to be troublesome. Foreign signals may also be picked up on open wire leads which may come into the cable which contains a carrier system. In most instances, however, the use of compandors or angular modulation techniques make it possible to operate channels without severe degradation in the presence of interfering frequencies.

6.7 From experience in REA borrowers' systems most troubles which have occurred in new installations of cable carrier systems involve some irregularity in the cable plant such as, bridged taps at splice points, loading coils or build out capacitors left in the pair, bad splices, etc. Once a clean carrier path is provided, the carrier will work satisfactorily.

7. APPLICATION ON BURIED PLANT

7.1 Buried cable offers a more stable carrier frequency path than aerial cable because the temperature of the cable remains fairly constant the year around. In buried plant applications the repeater spacing may be lengthened a slight amount, however, this is a recommendation entirely up to the carrier manufacturer since spacing is controlled by equalization and power feed limitations. Experience has shown that transistorized repeaters are susceptible to lightning damage on buried as well as aerial plant if they are not adequately protected. But as explained in paragraph 4 most carrier manufacturers have improved their protection practices such that during the 1963 lightning season few complaints were received in REA of lightning damage where the improved protection was installed.

7.2 On buried plant applications there are usually less open wire extensions off the buried cable and the susceptiveness to interference from foreign radio frequencies is reduced.

7.3 Water which might seep into a buried cable would change the attenuation and slope characteristics. Any water which might be present inside the sheath even though the wires of the pairs would be individually protected by conductor insulation would present a different dielectric than air and would adversely affect the carrier transmission characteristics. Care must be exercised in keeping moisture out of cable over which carrier will be operated. As stated previously carrier system regulation is designed to compensate for temperature variations and not for high losses caused by water. Should moisture become a problem the cable would have to be dried and can be pressurized. To this date water has not caused any known problems with carrier in REA borrowers' systems.

8. SUBSCRIBER CABLE CARRIER

8.1 Subscriber cable carrier offers a means of improving or providing excellent transmission to subscribers located at great distances from the central office. Transmission approaches that of toll quality circuits with respect to bandwidth, low transmission losses and low noise.

8.2 REA TE & CM-424, "Design of Subscriber Loop Plant," covers very thoroughly the limitations of voice frequency circuits. To meet minimum transmission requirements on long subscriber circuits it is necessary to use long line adapters, E-6 type voice frequency repeaters, battery boosters, etc. All of these additions to conventional practices may not be necessary if subscriber carrier can be proven in economically over voice frequency circuits. Section 424 states that voice circuits on long loop are possible up to 30 miles using the supplementary equipment mentioned above. Economic studies have shown that subscriber carrier on new plant begins to prove in at 18 miles. Also the use of

subscriber carrier does not entail investment in channels until the demand actually occurs. Additions in channels can be made as growth occurs and is a flexible method of expanding plant. Therefore, on long subscriber loops it behooves engineers to investigate the use of subscriber carrier.

8.3 Figure 9 illustrates how subscriber terminals of a carrier system are dropped off at intermediate points between the central office and far-end subscriber terminal. This illustration shows how 10 channels of a 20 channel carrier system can be dropped off along the cable. Other arrangements of carrier equipment make it possible to drop off 5 or 6 channels along the cable. At each subscriber terminal housing a group of channels, standby battery power is available in the event of a failure of the 117 volts a.c. power. Therefore, service reliability is not dependent on continuous a.c. power.

8.4 From the subscriber terminal, voice frequency extensions using conventional loaded cable facilities can be extended 10 to 15 miles. Thus, if the distance between the central office terminal and the subscriber terminal is 25 miles, subscriber loops up to 40 miles from the central office are possible.

8.5 As discussed in paragraph 5.6, if the repeater power limitations are overcome by special power feed arrangements multisystem operation of subscriber carrier is possible up to 40 miles between terminals. Therefore, 55 mile cable subscriber loops are possible (40 miles +15 miles). With the use of subscriber carrier it is possible to use aerial or buried cable plant in the sparsely settled rural areas and extend service to distances greater than the present 30 mile limitation of voice frequency cable circuits. At the present time sparsely settled areas use open wire subscriber carrier which is very often affected by ice and sleet on the open wire conductors. Subscriber cable carrier offers a way to provide hardened all weather facilities to the sparsely settled areas which require subscriber loops up to 55 miles.

8.6 To compute the effective transmission between distant subscribers and the COE when carrier is used reference should be made to REA TE & CM-910, paragraph 15.04, "Subscriber Carrier Equipment." In this section the voice frequency net loss through the carrier is recommended at 4 db. Depending on the carrier manufacturer's recommendation net loss as low as 2 db may now be used. Simply stated, the effective subscriber loop loss is computed for the voice extension connected to the subscriber terminal using the requirements of REA TE & CM Section 425, "Principles of 2-Wire Voice Frequency Subscriber Loop Transmission," or REA TE & CM-424, "Design of Subscriber Loop Plant." Afterwards, the carrier voice frequency net loss is added to this figure (2 db or 4 db) plus .5 db for central office loss and this will be the effective loss of the overall subscriber loop. Usually the overall effective transmission will be much better than the -1 db objective since the subscriber terminal has its own 48 volt talking battery power and is located near the group of subscribers served by the channel.

8.7 The net loss through the carrier is independent of the distance separating the central office and subscriber terminal. It can be either 10 miles or 40 miles just so the facility is adequate at carrier frequencies.

8.8 Cable subscriber carrier equipment is available where the subscriber terminal is pole mounted and provided with standby battery power. Repeaters are also powered from this terminal as previously discussed in this section.

9. TRUNK CABLE CARRIER

9.1 Low cost cable carrier for trunk use is highly recommended for expanding existing trunk groups and in new construction.

9.2 Meeting VNL+2 requirements by means of cable carrier is usually easier than the rehabilitation of many existing voice frequency circuits. Inherently carrier is superior to 2-wire voice frequency circuits in that carrier is effectively a 4-wire high velocity circuit.

9.3 The low cost cable carrier systems listed in REA's Acceptable List of Materials all meet at least minimum voice frequency response requirements of +1 db to -3 db with reference to 1000 cps from 300 to 3000 cps. On all properly installed low cost carrier systems the idle channel noise has been around 25 dbrnc (20 dba0) for most channels with a few as high as 30 dbrnc (noncompandored value). Circuits of this magnitude of quietness sometimes require that a white noise generator be activated to give the circuits a live quality and to mask out slight intermodulation effects or crosstalk. Carrier circuits have often been found to be so inherently quiet that barely perceptible crosstalk is audible. Noise generators can be used to mask this low level crosstalk but still not introduce any objectionable noise.

9.4 Numerous measurements have been made of echo return loss of all types of low cost cable carrier and most of the equipment has demonstrated excellent return loss characteristics.

9.5 Extensive dial pulse distortion measurements have been made on many short haul carrier systems on an E & M basis and no appreciable distortion has been introduced because of the carrier equipment.

9.6 The reliability of low cost cable carrier equipment cannot be attested to until more time in service is experienced. But, based on experience with transistorized open wire carrier equipment which has been in service for 5 years or more, transistorized equipment maintains voice frequency and carrier frequency levels far more stable than is possible on tube type equipment and channel reliability is improving rapidly.

9.7 REA recommends the use of low cost cable carrier for toll, EAS and subscriber use where it is economical to use carrier as compared with physical voice frequency circuits or other means for deriving trunk and subscriber loop plant.

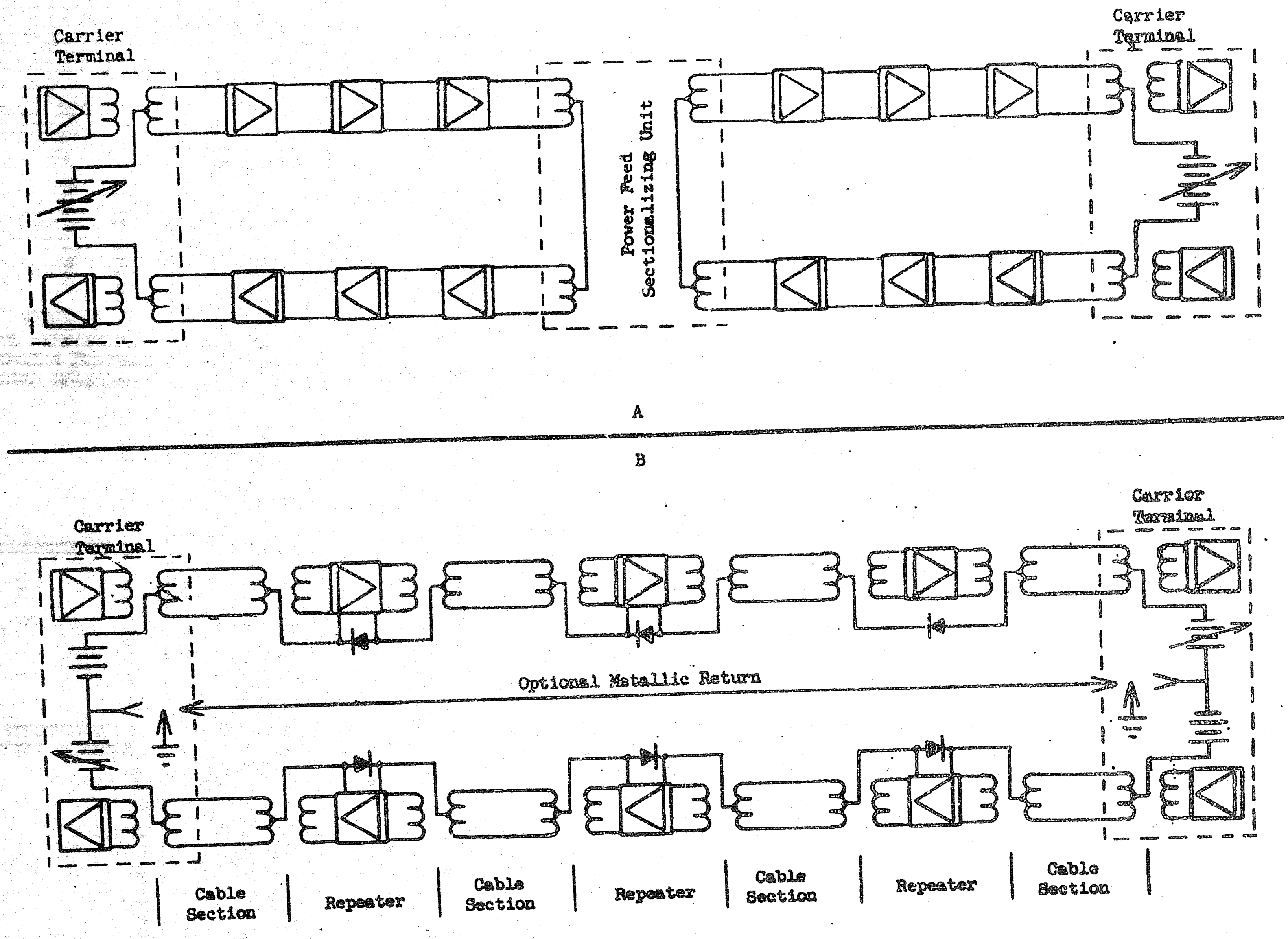


FIGURE 1

Two Methods of Powering Repeaters on Cable Carrier Systems

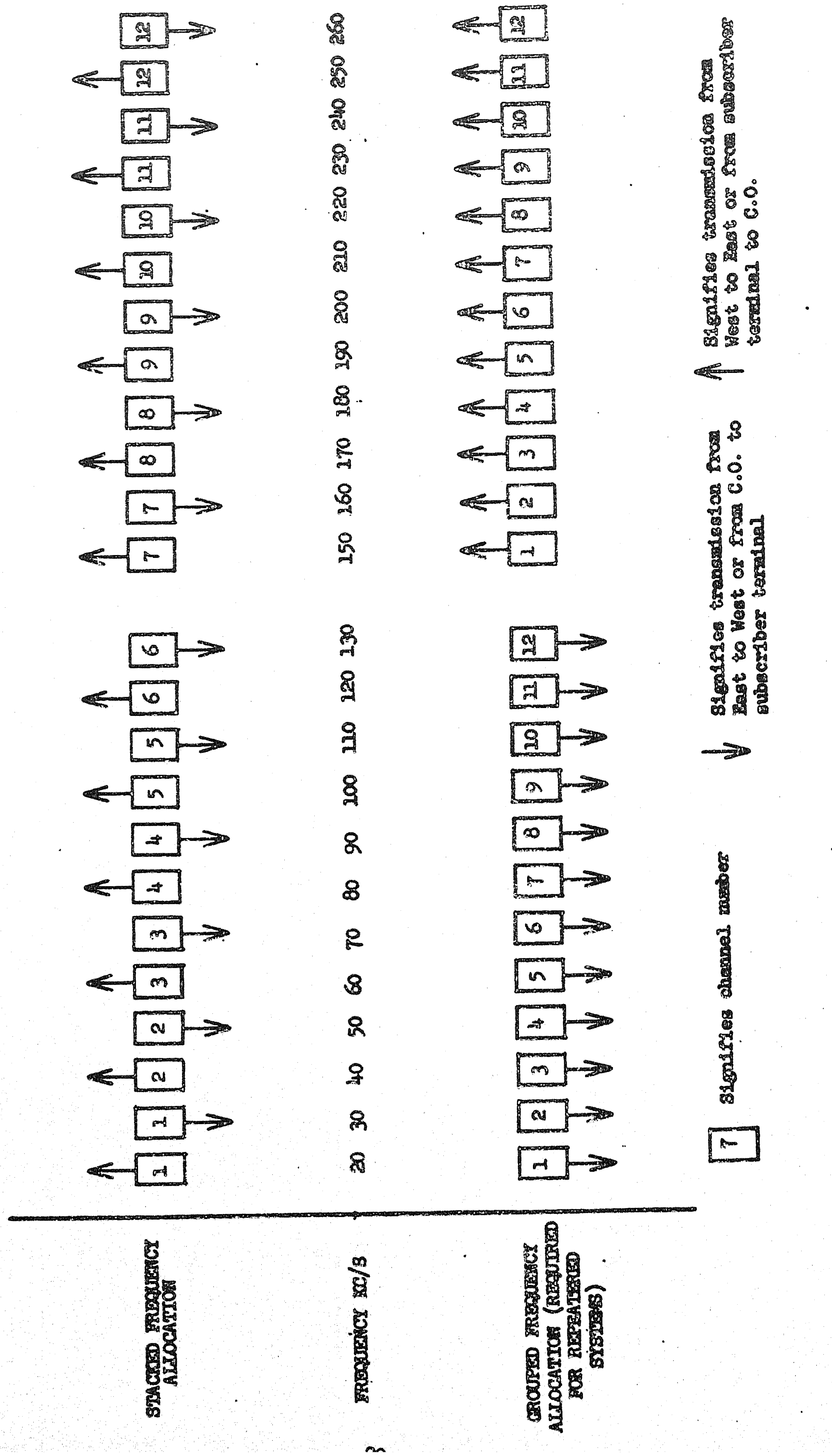
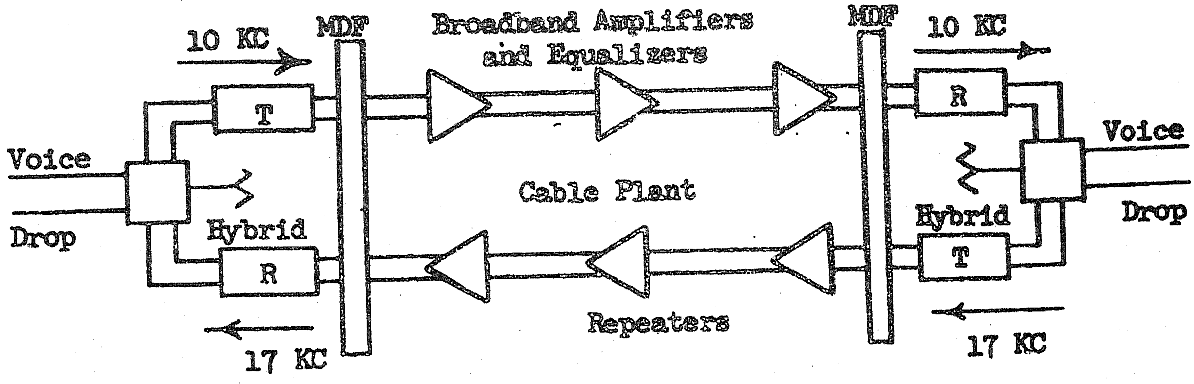

STACKED FREQUENCY ALLOCATION
FREQUENCY KC/S
GROUPED FREQUENCY ALLOCATION (REQUIRED FOR REPEATERED SYSTEMS)
20 30 40 50 60 70 80 90 100 110 120 130 150 160 170 180 190 200 210 220 230 240 250 260
Signifies channel number
Signifies transmission from East to West or from C.O. to subscriber terminal
Signifies transmission from West to East or from subscriber terminal to C.O.

FIGURE 2

Example of 4-Wire Carrier System



These repeaters are common to all 22 channels.

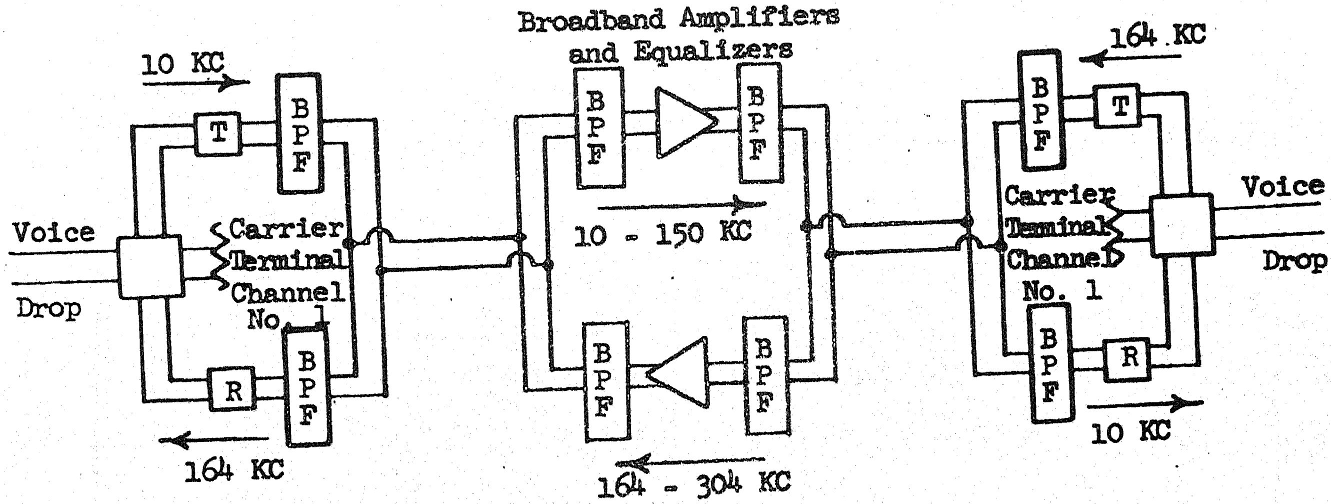
22 channels per system, 10 KC to 311 KC. Frequencies staggered for each direction of transmission by 7 KC.

Transmit	E to W,	10 KC - 304 KC
Transmit	W to E,	17 KC - 311 KC

Example of 2-Wire Carrier System

11 channels per system, 10 KC to 304 KC. Grouped frequencies for each direction of transmission

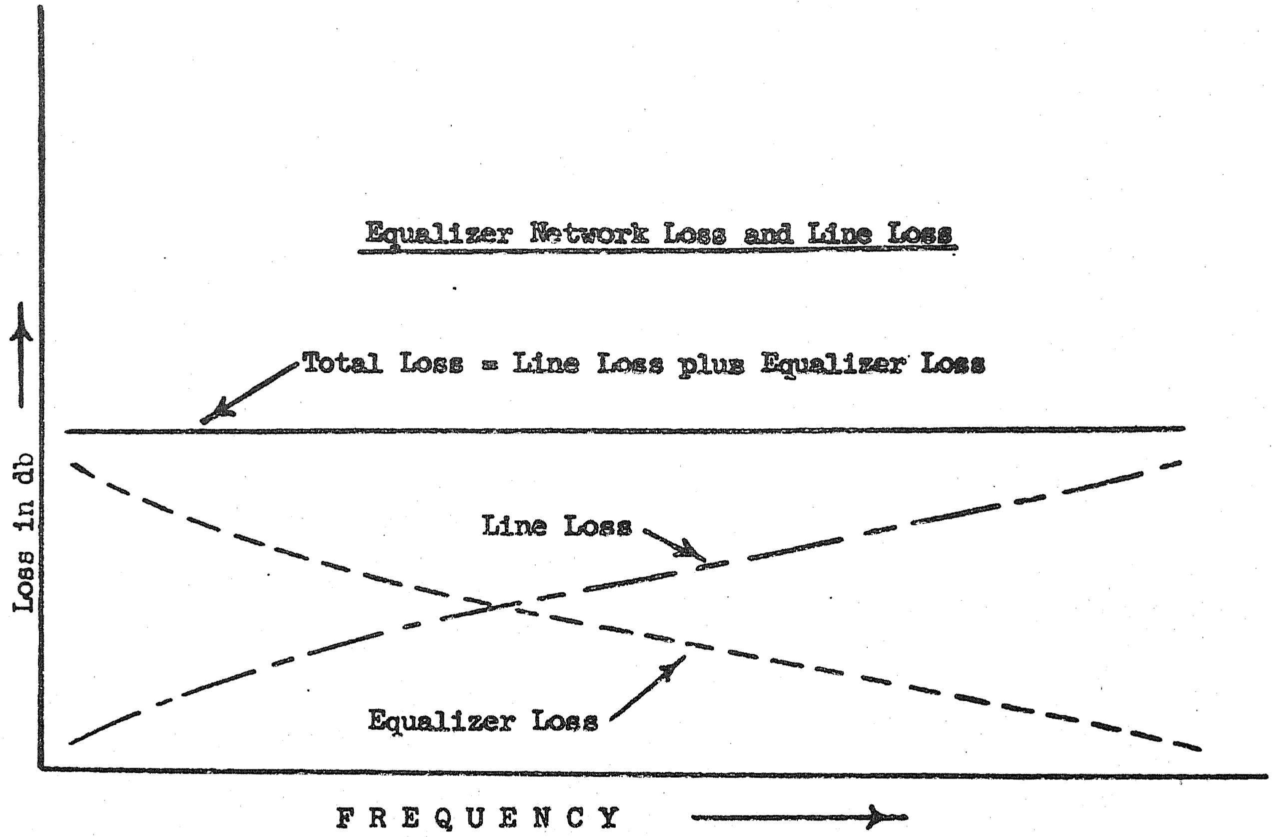
Transmit	E to W,	10 KC - 150 KC
Transmit	W to E,	164 KC - 304 KC



This repeater is common to all 11 channels of carrier system.

BPF - Band Pass Filter

Figure 3



An Application of Broadband Carrier Repeaters
to Cable Plant on a 4-Wire Basis

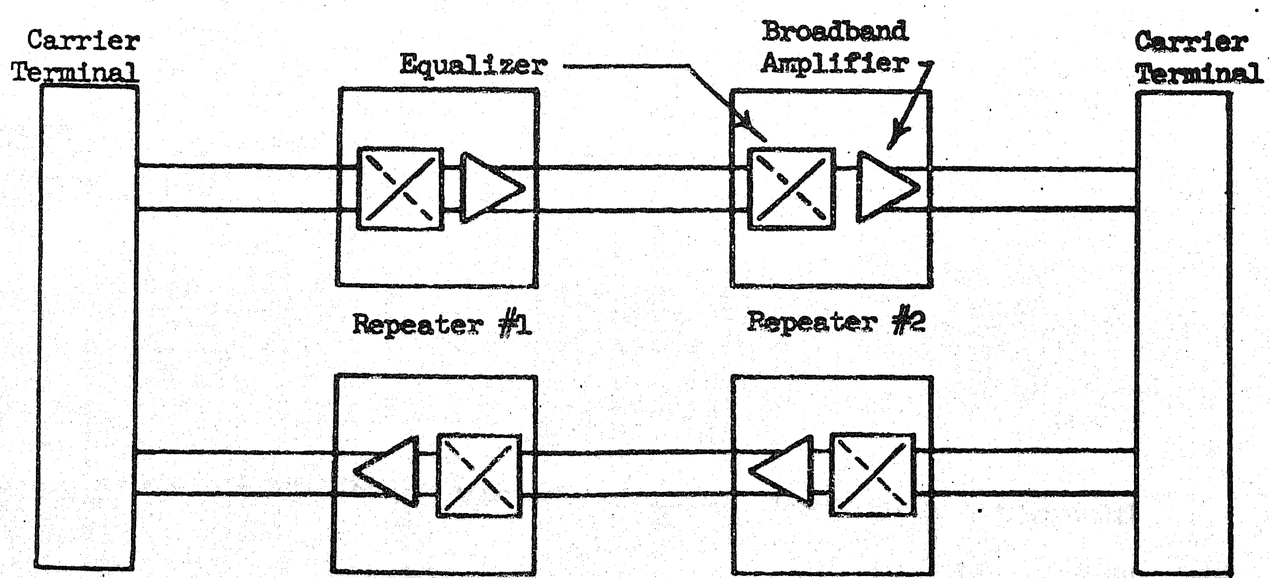


Figure 4

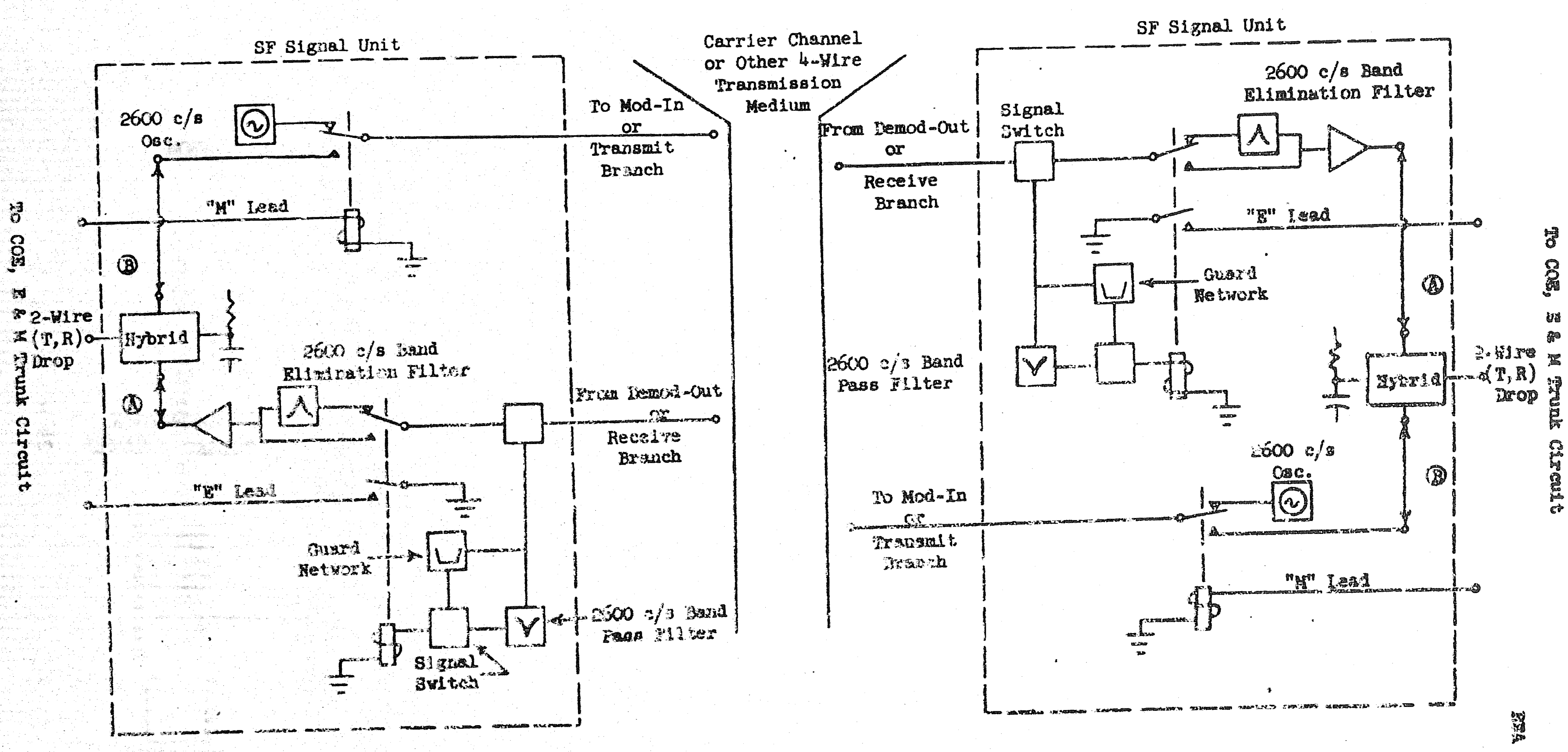
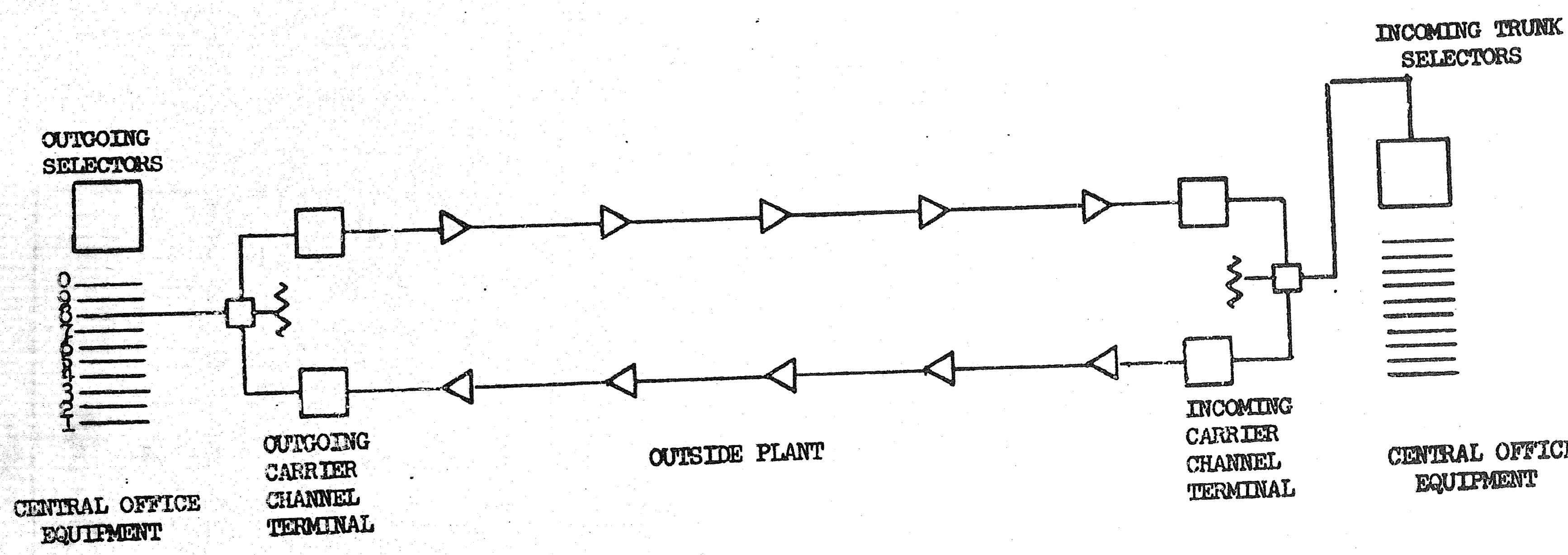


FIGURE 5

Single Frequency (SF) Inband Signaling
(Idle or On-Hook Condition)



NOTE: THERE IS NO NEED FOR A COE TRUNK CIRCUIT WITH ONE-WAY LOOP DIAL CARRIER

CONNECTION OF ONE-WAY LOOP DIAL CARRIER TO CENTRAL OFFICE EQUIPMENT

FIGURE 6

REDUCTION IN CROSSTALK LOSS IN CABLE VERSUS FREQUENCY

$$\text{DB REDUCTION} = 20 \log \frac{\text{"X" KC}}{150 \text{ KC}}$$

THIS FORMULA IS FOR THE COMPUTATION OF DB CROSSTALK REDUCTION AS FREQUENCY INCREASES WITH RESPECT TO 150 KC WHICH IS THE SPECIFIED FREQUENCY OF REA FAR END CROSSTALK REQUIREMENTS.

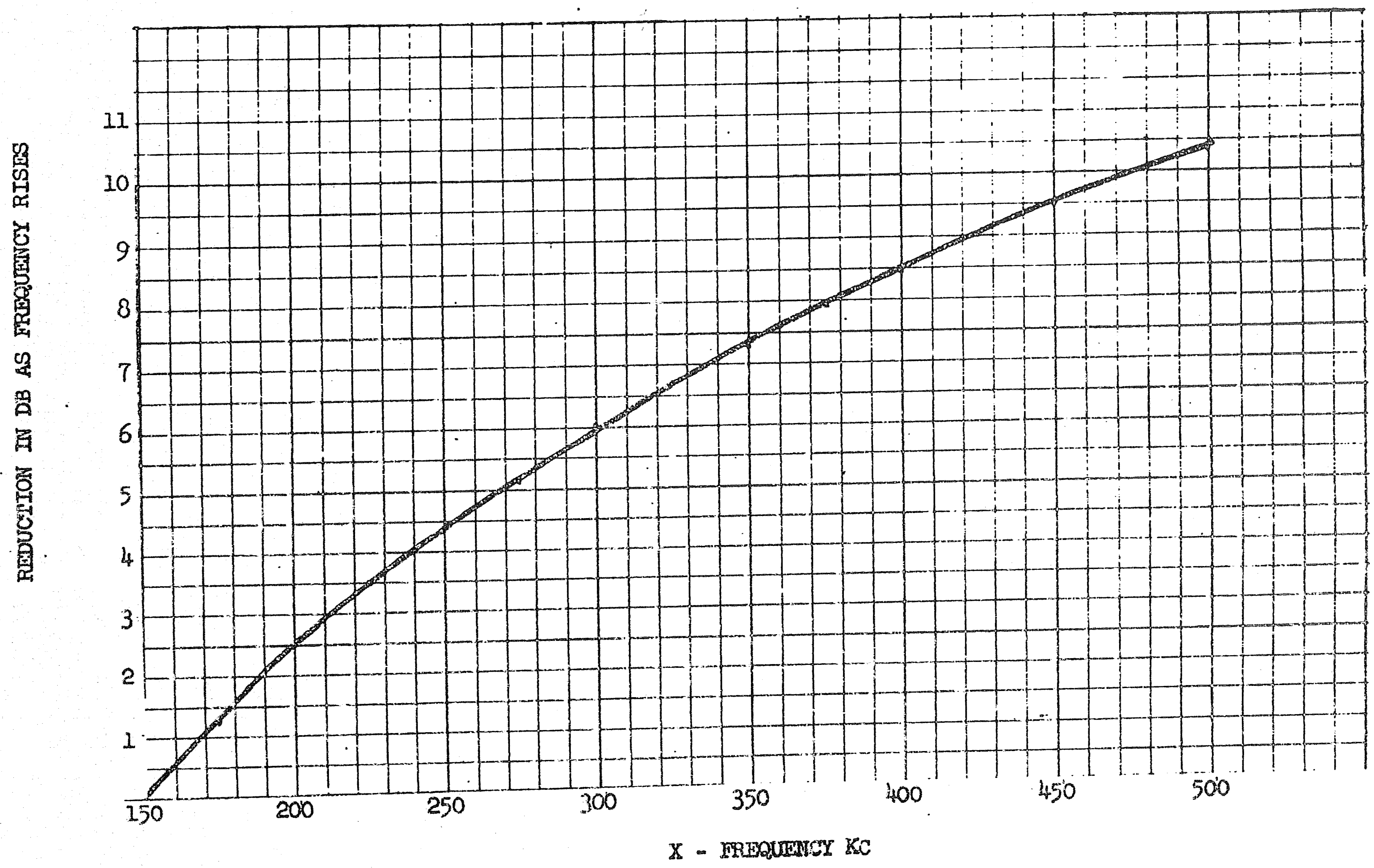


FIGURE 7

REDUCTION IN CROSSTALK LOSS IN CABLES AS LENGTH INCREASES

$$\text{DB REDUCTION} = 10 \log_{10} (\text{X MILES}) \left(\frac{5280 \text{ FT.}}{1000 \text{ FT.}}\right)$$

THIS FORMULA IS FOR THE COMPUTATION OF DB CROSSTALK REDUCTION AS LENGTH INCREASES WITH RESPECT TO 1000 FT. LENGTHS 1000 FT. IS THE SPECIFIED LENGTH OF REA FAR END CROSSTALK LOSS REQUIREMENTS

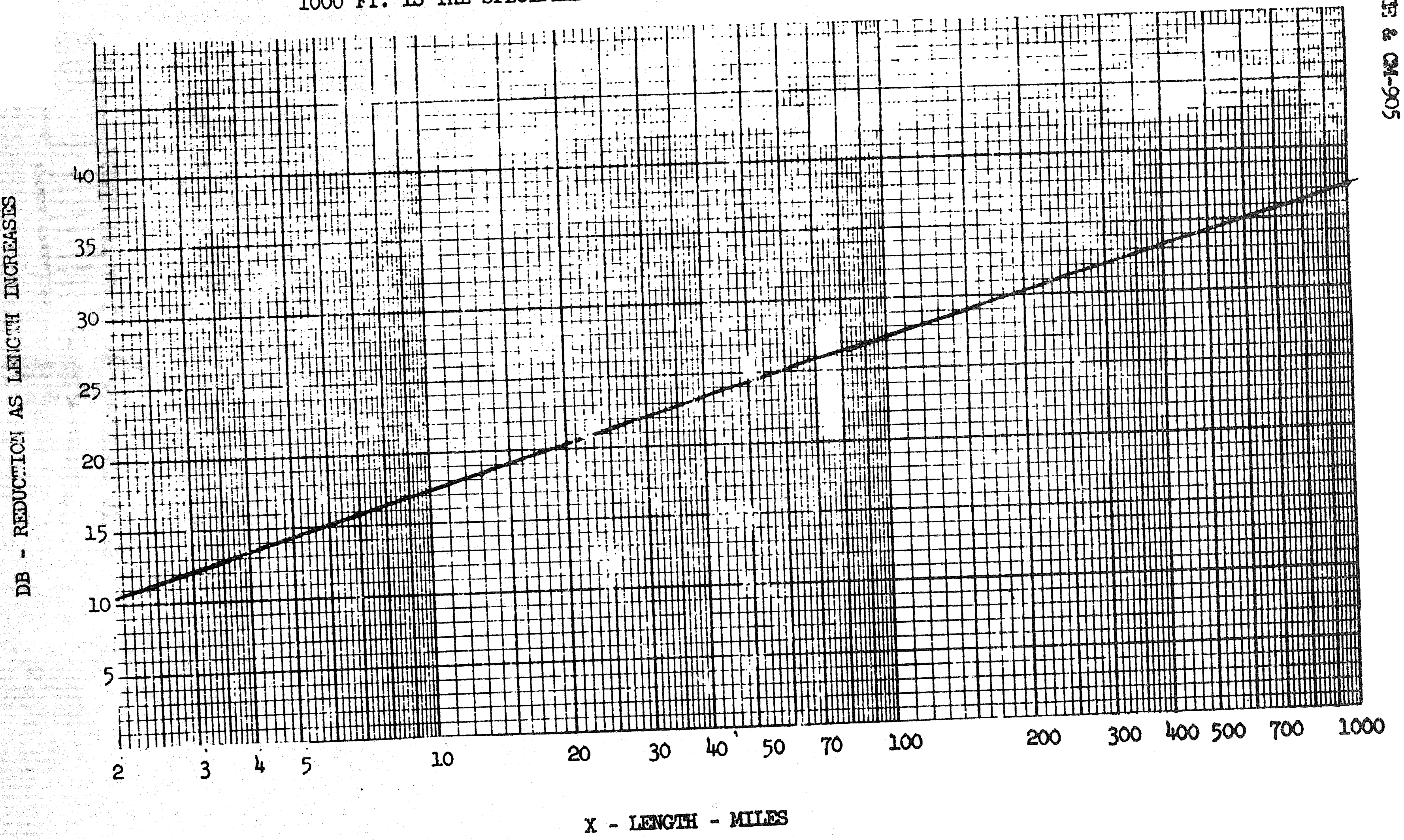
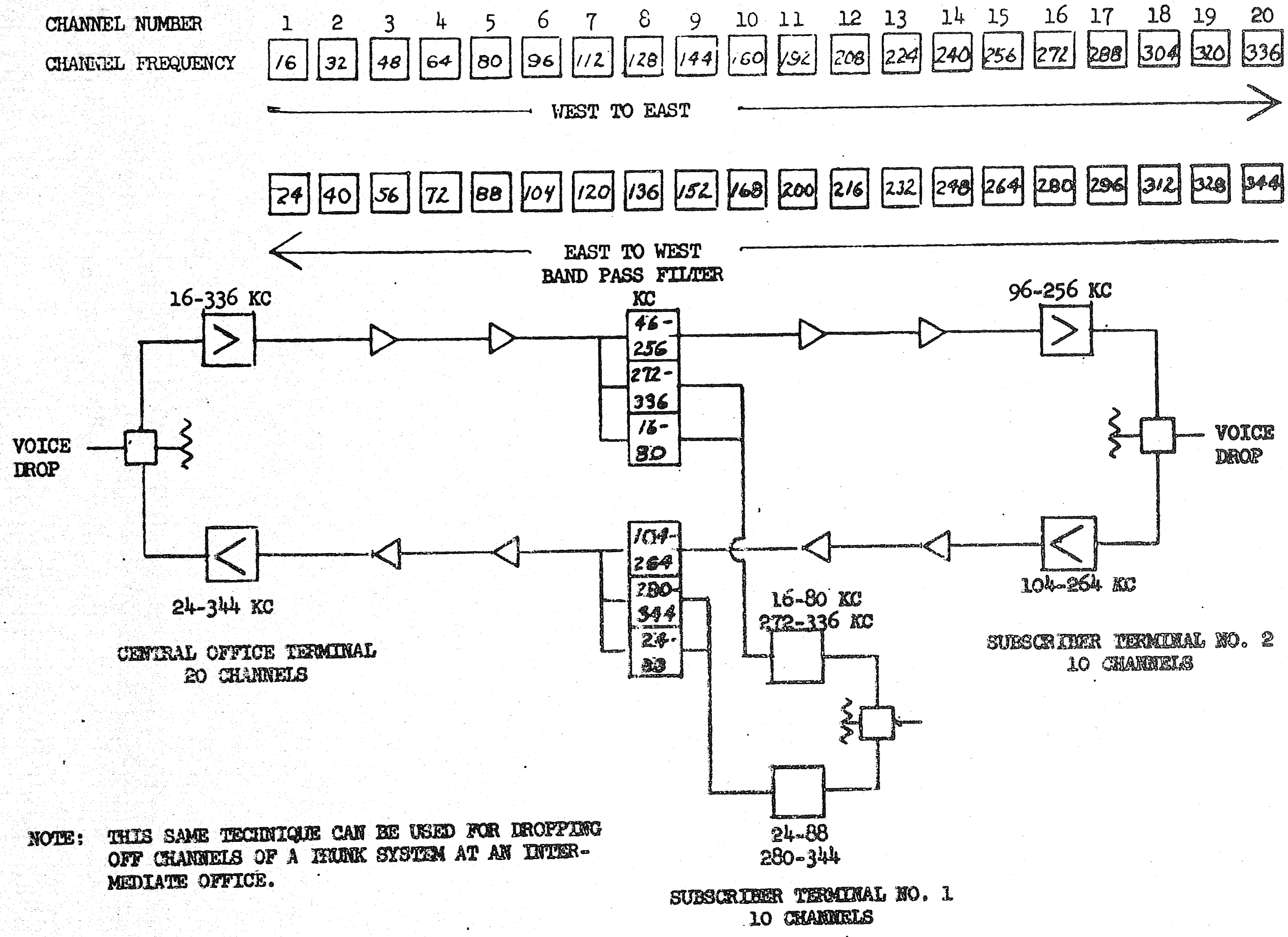


FIGURE 8



NOTE: THIS SAME TECHNIQUE CAN BE USED FOR DROPPING OFF CHANNELS OF A TRUNK SYSTEM AT AN INTERMEDIATE OFFICE.

SUBSCRIBER CABLE CARRIER

FIGURE 9